MEMS Tunable Antennas

Reaching for the 600 MHz-bands

Barrio, Samantha Caporal Del; Morris, Art; Pedersen, Gert Frølund

Published in:
Antennas and Propagation in Wireless Communications (APWC), 2014 IEEE-APS Topical Conference on

DOI (link to publication from Publisher):
10.1109/APWC.2014.6905571

Publication date:
2014

Document Version
Early version, also known as pre-print

MEMS Tunable Antennas: Reaching for the 600 MHz-bands

Samantha Caporal Del Barrio *† Art Morris † Gert F. Pedersen *

Abstract — **Addressing low frequency bands is challenging on small platforms. Tunability is a promising solution to cover the bandwidth required for 4G mobile communication. The work presents two designs and shows that for comparable efficiency and bandwidth, the tunable antenna occupies half the volume required by the wide-band antenna.**

1 Introduction

Driven by the mobile users demand, the pressure on data rates is ever increasing. In order to improve connectivity, the 4^{th} Generation (4G) of mobile communications was standardized. For antenna engineers, the two main challenges that 4G raises are the bandwidth extension and the need for multiple antennas [1]. They are contradictory in the sense that widening the antenna bandwidth requires to enlarge its volume in order to maintain a good efficiency [2]; whereas fitting more antennas into current phone form factors requires low-profile designs. Therefore, the real challenge is to extend the antenna bandwidth while reducing its volume. 4G has extended the radio frequency spectrum of mobile communications from 698 MHz to 2.69 GHz [1], and the auction on the 600 MHz-band is soon taking place [3]. It is well known that at low-bands the ground plane plays a major role in the radiation mechanism of the antenna. However, at 600 MHz, even the largest dimension of a typical phone is less than a quarter of the wavelength. Thus, reaching for lower frequencies while maintaining antenna volume has led to dramatic efficiency degradation, as reported in [4] for commercial phones.
Frequency-Reconfigurable Antennas (FRA) are antennas that can modify their resonance frequency, while keeping a fixed size. For example capacitively loaded antennas will see their resonance frequency decrease as the capacitance increases [5]. Combined with Micro-Electro-Mechanical Systems (MEMS) tunable capacitors − state-of-the-art in terms of insertion loss and voltage handling [6] −, FRA are the most promising way to address low frequency bands, while complying with today's market requirements on efficiency and antenna volume.

*Section of Antennas, Propagation and Radio Networking (APNet), Department of Electronic Systems, Faculty of Engineering and Science, Aalborg University, {scdb,gfp}@es.aau.dk

†Wispry Inc, Irvine, USA, art.morris@wispry.com

This paper aims at comparing the properties of a narrow-band FRA to a wide-band antenna, both addressing the 600 MHz-bands. Given the same overall bandwidth and efficiency, the comparison addresses antenna dimensions, surface currents and potential on antenna isolation.

2 Theoretical limits on small antennas

An antenna falls into the category of Electrically Small Antenna (ESA) when $ka \leq 0.5$, where k is the free space wavenumber, and a is the radius of an imaginary sphere circumscribing the maximum dimension of the antenna. For antennas placed on an electrically small ground plane, as is the case for mobile phones operating at frequencies below 1 GHz, the ground plane must be included in the circumscribing sphere. Indeed, in the low bands of 4G the ground plane is part of the radiating structure, i.e. part of the antenna.

For linear and passive antennas exhibiting single impedance resonance within their defined VSWR bandwidth, their Quality factor (Q) can be related to their size, bandwidth (BW) and efficiency (η) [7]. The low bound on the antenna Q (Q_{lb}) for a given frequency (ω) relates to the antenna volume following Eq. (1). The η term in Eq. (1) shows that the lossier the antenna, the lower the Q_{lb}. Additionally, Q is inversely related to the Fractional Bandwidth (FBW) of the antenna at a given Voltage standing wave ratio (V) of value s, as described by Eq. (2). Therefore, the low bound on Q is an upper bound on bandwidth. Hence, lossier antennas exhibit a higher upper bound on achievable bandwidth ($FBW_{V,ub}$). The antenna volume relates to $FBW_{V,ub}$ following Eq. (3). Eq. (3) gives the maximum achievable bandwidth in a constraint volume. The upper bound on bandwidth at -6 dB return loss ($BW_{ub,-6dB}$) is plotted in Fig. 1 for different efficiencies and different values of ka, at 600 MHz.

$$Q_{lb}(\omega) = \eta \left(\frac{1}{(ka)^3} + \frac{1}{ka} \right) \tag{1}$$

$$Q(\omega) = \frac{2\sqrt{\beta}}{FBW_V(\omega)}, \sqrt{\beta} = \frac{s-1}{2\sqrt{s}} \tag{2}$$

$$FBW_{V,ub}(\omega) = \frac{2\sqrt{\beta}(ka)^3}{\eta(1+(ka)^2)} \tag{3}$$

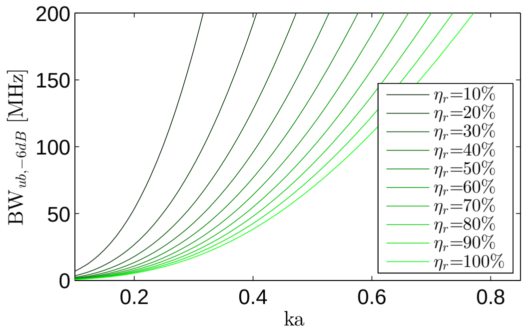
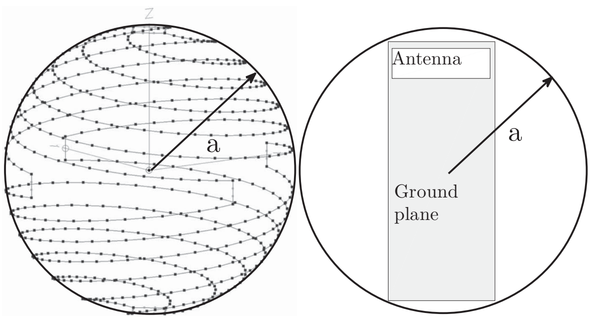


Figure 1: Achievable BW at 600 MHz, see Eq. (3).



(a) Folded spher. helix [8]. (b) Mobile phone antenna.

Figure 2: Antennas and circumscribing sphere

In [8], the author has designed and built antennas approaching the limit on achievable bandwidth. The work shows that in order to enhance its bandwidth, the antenna needs to best utilize its volume. In other words the antenna design needs to fill the volume defined by the sphere circumscribing the antenna, to approach the maximum achievable bandwidth. A well known example of a low-Q antenna is the folded spherical helix from [8], depicted in Fig. 2a. However, with mobile phone antennas, the designers do not have such degrees of freedom, as the size and shape of the ground plane are fixed. Moreover, the locations of the feed and of the antenna are often predetermined. An example of a typical top mounted antenna is given in Fig. 2b, where one can see that the quasi-majority of the circumscribing sphere cannot be utilized for the antenna design. Consequently, achievable bandwidths on mobile phone platforms are narrower. In order to predict and enhance achievable bandwidths on mobile phone platforms, one needs to apply the theory of characteristic modes [9]. A comprehensive overview is given in [10], detailing the ground plane modes and the trade-offs related to excitation location. It is also shown that for low frequencies, an excitation on the short edge or on the corner of the board will most efficiently excite the wanted mode.

3 Antenna designs

This section proposes two antenna designs: a narrow-band FRA and a wide-band antenna. The wide-band antenna covers simultaneously all the bands from 600 MHz to 960 MHz, while the FRA exhibits a narrow instantaneous bandwidth, that can be reconfigured to all frequencies between 600 MHz and 960 MHz. The proposed antennas are designed on a 120 mm $\times$ 55 mm FR-4 ground plane. Obtaining wide bandwidths is challenging, as at 600 MHz the wavelength is 0.5 m. To make fair comparisons between the proposed antenna types, the antennas are designed for the same total efficiency.

3.1 Wide-band antenna design

In nowadays mobile phones, the limited available volume to fit the antenna causes the antenna impedance to have a small real part and a large imaginary part, at low frequencies. In other words, the antenna is difficult to match to the 50 Ω feed line and the the amount of power that can be radiated is low. Moreover, the wider the bandwidth is, the more difficult the matching becomes, if one considers all frequencies simultaneously. Typically matching circuitry at the feed is necessary, at the cost of additional loss.

The proposed wide-band design is based on Capacitive Coupling Element (CCE) techniques, described in [11]. CCEs excite the board resonance to enhance bandwidth. In order to achieve the maximum bandwidth the CCE is located very close to the ground plane, on one of the short edges and fed in its center. A wide-band match is made with matching fixed components at the feeding line. The antenna design is detailed in Fig. 3, as well as the feed matching circuitry. The antenna is placed 1 mm above the ground plane and fed in its center. The width of the antenna is 10 mm, as slimness is essential for phone designs. However, a larger width would improve the matching of the antenna to the 50 Ω feed line and reduce mismatch loss. The dimensions of the proposed design lead to a mechanical volume of 1.65 cc.

3.2 Narrow-band FRA design

The FRA design is a monopole placed on top of the ground plane, and fed through coupling. The monopole is connected to a MEMS tunable capacitor [13], in order to modify the reactive part of its impedance, thus its resonance frequency. The tuning range is [0-4] pF with a resolution of 62 fF. The FRA design is shown in Fig. 4. Both the width (5 mm) and the height (6 mm) of the monopole control the bandwidth. Because of the tuning prop-

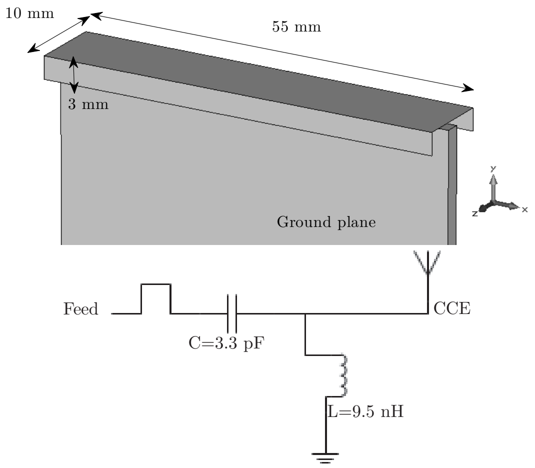


Figure 3: Wide-band antenna design.

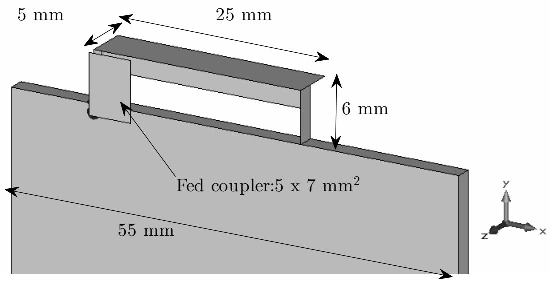


Figure 4: FRA antenna design.

erty of the design, the instantaneous bandwidth can be narrow, thus the antenna dimensions can be small. Additionally, the antenna is well match on its instantaneous bandwidth, thus limiting mismatch loss. However, the tuning component brings insertion loss to the total efficiency. The dimensions of the proposed design lead to a mechanical volume of 0,75 cc for the radiator.

4 Simulations and measurements

The excitation of the ground plane depends on the antenna element and its radiation mechanism. The wide-band antenna needs to fully exploits the ground plane in order to cover the required frequency range. Fig. 5 shows full excitation of the ground plane by the CCE, as opposed to confined fields around the FRA element.

A major consequence of the ground plane excitation type is the potential for electromagnetic isolation. 4G standards require Multiple-Input Multiple-Output (MIMO) operation, i.e. several antennas at the user terminal and the base station. To provide a MIMO gain the antennas need to be isolated, which is challenging on small terminals, where the maximum dimension is smaller than $\lambda/2$.

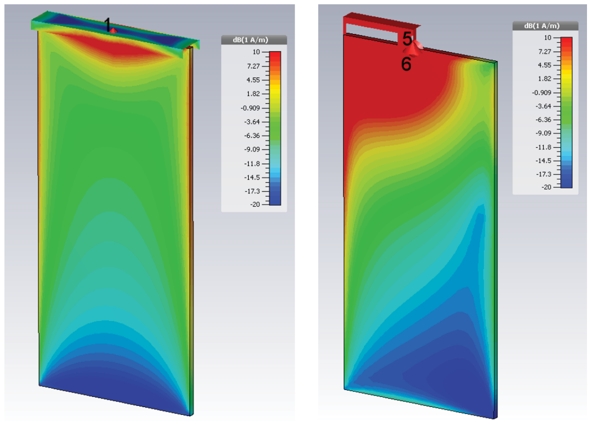
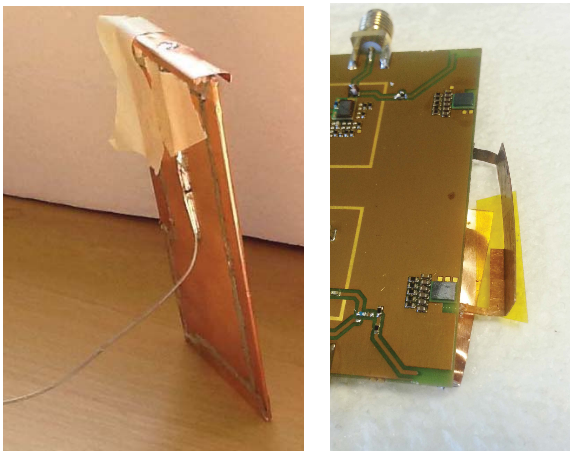


Figure 5: Current distributions on the wide-band antenna (left) and on the FRA (right) at 600 MHz.

In the case of the wide-band antenna, a location for the secondary antenna that excites the same ground plane mode will result in very high antenna coupling. The theory of characteristic modes provides a tool to find a location that either excites a different mode of the ground plane, either does not excite the ground plane at all. In both cases, the secondary antenna will be less efficient. In the case of the FRA, the ground plane is not fully used by the antenna, therefore the location of the secondary antenna is more flexible. It can also benefit from part of the ground plane radiation, leading to similar efficiency for both main and secondary FRAs. Fields are intrinsically confined around the FRA, thus allowing for several feed locations on the board, where antenna coupling is low.

Both antenna designs have been built. They are shown in Fig. 6a and Fig. 6b. In Fig. 6a, one can see how the cable is led out in a low current location, in order to limit its interaction with the ground plane radiation. The antenna impedances are shown in Fig. 7 and Fig. 8 respectively. The bandwidth of the FRA shrinks from 20 MHz to 5 MHz, as it is tuned. The measured resonance of the wide-band antenna is slightly off compared to the simulated values, due to building imprecision. Additionally, in order to cover the required bandwidth and exhibit small dimensions, the wide-band antenna has a very poor match. A similar method was observed in the first commercial LTE-phone [14], in order to add the bands at 700 MHz. Increasing the antenna width improves the match, at the cost of the phone thickness. Poor match translates into poor efficiency (η), as total η is the sum of radiation and mismatch η. Efficiency plots are shown in Fig. 9 and Fig. 10. The insertion loss of the tuner is part of the radiation η of the FRA.



(a) Wide-band antenna. (b) FRA.

Figure 6: Mock-ups.

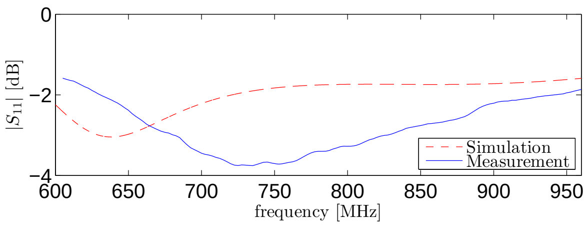


Figure 7: Measurement of the wideband antenna.

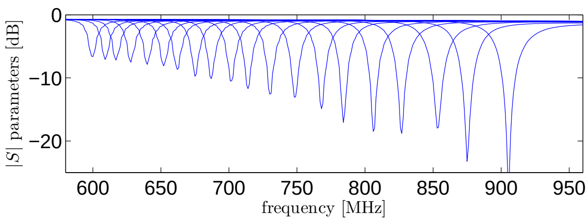


Figure 8: Measurement of the FRA.

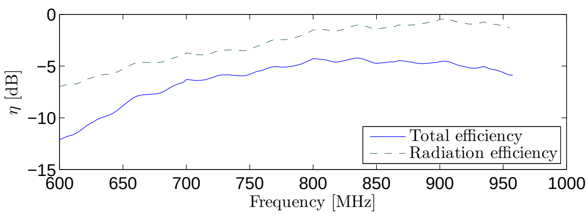


Figure 9: Measured efficiency wide-band antenna.

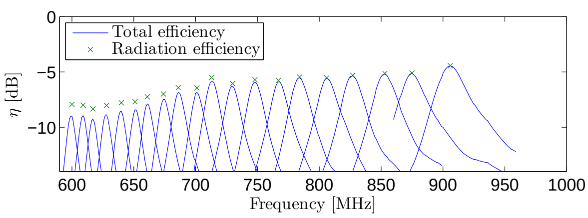


Figure 10: Measured efficiency of the FRA.

5 Conclusion

This paper has shown and compared two conceptually different antenna design: a narrow-band FRA and a wide-band antenna. They both address the low-bands of LTE, including the future 600 MHz bands. For comparable total bandwidth and efficiency, the narrow-band FRA occupies less than half the space needed for the wide-band antenna. Additionally, the FRA presents higher potential for antenna isolation. FRA are the most promising way of addressing the low frequency bands of LTE on small terminals.

References

[1] 3GPP TS36.101, "LTE; Evolved Universal Terrestrial Radio Access (E-UTRA)," 2013.

[2] R. F. Harrington, "Effect of Antenna Size on Gain, Bandwidth, and Efficiency," *Journal of Research of the National Bureau of Standards- D. Radio Propagation*, vol. 64D, 1960.

[3] www.dailywireless.org"600MHzAuction"2013.

[4] A. Tatomirescu et.al., "Body-loss for Popular Thin Smart Phones," in *(EUCAP)*, pp. 3754-3757, 2013.

[5] A. James, "Reconfigurable Antennas for Portable Wireless Devices," *IEEE Antennas and Propagation Magazine*, vol. 45, no. 6, pp. 148-154, 2003.

[6] P. Gammel, et.al., "RF MEMS and NEMS technology, devices, and applications," *Bell Labs Technical Journal*, vol. 10, pp. 29-59, 2005.

[7] S. R. Best, "Electrically Small Multiband Antennas," in *Multiband Integrated Antennas for 4G Terminals* (D. A. Sanchez-Hernandez, ed.), ch. 1, pp. 1-32, Artech House, 2008.

[8] S. R. Best, "A Study of the Performance Properties of Small Antennas," in *Antenna Applications Symposium*, pp. 193-219, 2007.

[9] R. F. Harrington et.al., "Theory of Characteristic Modes for Conducting Bodies," *IEEE Transactions on Antennas and Propagation*, vol. 19, no. 5, pp. 622-628, 1971.

[10] H. Li et.al., "Characteristic Mode Based Tradeoff Analysis of Antenna-Chassis Interactions for Multiple Antenna Terminals," *IEEE Transactions on Antennas and Propagation*, vol. 60, pp. 490-502, 2012.

[11] Vainikainen et.al., "Resonator-Based Analysis of the Combination of Mobile Handset Antenna and Chassis," *IEEE Transactions on Antennas and Propagation*, vol. 50, no. 10, 1433-1444, 2002.

[12] WiSpry Tunable Digital Capacitor Arrays (TDCA), "www.wispry.com"

[13] S. Caporal Del Barrio and G. F. Pedersen, "Correlation Evaluation on Small LTE Handsets," in *VTC Fall*, pp. 1-4, 2012.